ALTERNATE CURRENT MACHINERY—INDUCTION ALTERNATORS.

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In the following pages it is proposed to discuss some of the elementary phenomena found while studying the performance of alternators excited by alternating currents. In a second paper the writer intends to deal with the practical application of the principles here described.

It occurred to the writer a number of years ago that if the field of an alternator is made by alternating instead of continuous currents, the variations of current in the armature, both in value and phase, due to changes of resistance or inductance in the work circuit of the machine, would produce corresponding changes in the value and phase of the field currents, because the value of the field producing currents under these conditions is determined by the inductance of the field circuit, and this inductance is varied in value by armature reaction. And, because the writer long ago devised the following simple rule for predicting the flow of periodic currents in circuits, where the phenomena of distribution were not entirely clear at first sight; namely, that periodic currents attempt to flow in a network of connected circuits, or in circuits possessing mutual induction, so as to produce the least possible magnetism, (flow at such time and value as to destroy each other's fields).

The alternators to be described have their rotors and stators wound with distributed windings. The rotor circuits are supplied with very low-frequency multiphase currents, as shown in Fig. 1. These currents produce a field, or fields, which move around the rotor at a speed proportional to the frequency of the magnetizing or exciting source.

If the connection of the multiphase exciter circuits is such as to produce a clockwise electromagnetic rotation of the field (rotor), the rotor structure of the alternator may then be mechanically revolved either in the same or in an opposite direction.

Let n be the frequency of the exciting circuit and n_1 the frequency of mechanical rotation; then if the electromagnetic and mechanical rotations are in the same direction the speed of the flux will be proportional to $n_1 + n$; if they are in opposite direction to $n_1 - n$, and, as will be shown, these two relative arrangements produce very different phenomena.

Call $n_1 + n$ or $n_1 - n = n_{11}$ the frequency of the currents induced in the stator or armature conductors of the machine; evidently when $n = n_1$, $n_1 - n = 0$, and there is a stationary field in the space opposite to the stationary armature conductors; consequently, no electromotive force is induced.

FIG. 1.

Suppose, however, that n is small compared to n_1 ; for example, let the exciting frequency $n = 1$ cycle, while the frequency of rotation $n_1 = 61$ cycles; then

$$n_1 - n = 60 \text{ cycles,}$$

$$n_1 + n = 62 \text{ cycles.}$$

Consider the first case for a moment. Suppose the stator, or armature, of the alternator is supplying current to an external circuit; then, if we have a clockwise rotation (revolutions per minute) of 61 cycles and a counter-clockwise electromagnetic rotation (exciting current) of 1 cycle, the effective field rotation is clockwise and 60 cycles; consequently, the armature (stator) currents are also of 60 cycles frequency. But these stator currents produce a field in the air-gap of the machine and this field revolves synchronously with the rotor induction, *but not* synchronously with the rotor conductors, for they (the conductors) are going faster, viz., at the rate of 61 cycles. They

are therefore *constantly overtaking* the stator-produced field, and *passing through* it. That is to say, cutting it, and they therefore have electromotive force induced in them of a frequency = $61 - 60$ cycles = 1, = n , the exciting frequency; the final result being that an electromotive force of the same frequency as that of the exciting current is produced in the rotor (field) conductors, by simply loading the alternator in the usual manner.

This "stator induced electromotive force" in the rotor conductors (so we call it) is evidently proportional to, and in quadrature with, the stator current. It is zero when the stator current is maximum; maximum when the stator current is zero, etc. It is of the utmost importance in the phenomena to be described, for if the rotor circuit be of low resistance (great time-constant) the "stator induced electromotive force" in the rotor will produce a current (called "stator induced current") approximately *equal* in value, nearly *opposite in phase* to the stator current and, consequently, competent to neutralize the magnetomotive force of the armature or stator circuit and to destroy almost completely the magnetization due to the stator winding. In such an alternator there should be, then, no armature reaction, no back magnetization, no distortion of the field of the machine.

At first sight it would seem that these machines should give a constant electromotive force at all loads; when excited at constant potential they do not do this, but they give, when properly designed, a gradually rising potential at power-factor = 1 with a slight drop of potential for lower power-factors down to power-factor = 0.

In Figs. 2 and 3, Mr. Faccioli has represented the phase relations of the electromotive force, currents, etc., when (Fig. 2) the effective frequency of the alternator is equal to the difference between the rotational and magnetizing frequencies, and (Fig. 3), when it is equal to their sum.

In the diagram here given the ratio of the rotor to the stator turns is assumed to be 1:1; the ohmic and inductive resistance of the exciter is zero, that is to say, the exciter is assumed to maintain a constant terminal potential.

In the case of Fig. 2 ($N_{\text{r}} = N_1 - N$) the flux of the alternator rotates in one direction regarding the rotor and in the opposite direction regarding the stator; therefore Diagram 2 is supposed to rotate in the direction *R* regarding the rotor and in the direction *S* regarding the stator.

force e_R , at the terminals of the rotor; a part of the same flux proportional to vi_0 , will induce an electromotive force e_S at the terminals of the stator.

Now consider the case in which the machine is loaded by the current I_s at power-factor 1. The current I_s of the stator (armature) induces at the terminals of the rotor (field) an electromotive force in the direction E , proportional to the frequency of excitation of the machine. The electromotive force E produces in the rotor a current I_r which lags behind E by the angle ϕ . I_s and vi_r give a resultant j_s , whose magnetomotive force is superimposed on the original magnetomotive force vi_0 , giving a resultant magnetomotive force i_m , which is in quadrature with I_s . The electromotive force of the stator is E_s in quadrature with i_m and therefore in phase with I_s .

In the case of Fig. 3 when ($N_{II} = N + N_1$), the diagram rotates in the same direction regarding the stator and the rotor. The same symbols represent the same quantities as in Fig. 2. In this case the electromotive force e_s and e_r have the same direction, and the resultant magnetomotive force j_s has such direction as to decrease the original magnetization vi_0 of the machine; while in the case of Fig. 2, the magnetomotive force j_s , due to the load currents, has the effect of increasing the no-load magnetization of the machine.

When, therefore, the generated frequency of the machine is equal to the difference of the frequency of rotation and the frequency of excitation the magnetization of the machine may be higher when loaded with non-inductive load than when running free; this result being principally due to the resistance of the rotor or field, which prevents the current I_r from lagging exactly 90° behind E and consequently neutralizing the magnetomotive force of I_s .

On the other hand, the resistance of the rotor when the generated frequency is equal to the sum of the frequency of rotation and the frequency of excitation, has the effect of decreasing the magnetization of the machine when loaded with non-inductive load.

If the rotor of the machine had zero resistance and perfect mutual induction, then the rotor current I_r would lag exactly 90° from its electromotive force in both Fig. 2 and Fig. 3, and would be exactly equal and opposite to the stator current I_s . There would be no resultant magnetomotive force due to the load and therefore j_s would be equal to zero and the machine

would have constant electromotive force at any load and at any power-factor.

It then appears that if a machine of this type; that is, a machine with almost perfect mutual induction and very low resistance, could be built, there would be very little difference in its regulation when excited by forward and backward running fields. The principal difference would consist in the fact that with a forward running excitation the exciter would supply energy to the alternator in proportion to the ratio of the exciting to the generated frequency, while with the backward running excitation, the exciter delivers no energy to the alternator but receives energy from it.

FIG. 4.

It is interesting to study the regulation of the system at power-factors less than unity and examine the effects of variation of exciting frequency. This has been set forth by Mr. Faccioli in the following diagrams:

First, take up the case of the backward rotation of the field. In Fig. 4, I_s is the load current of the machine. The electromotive force E induced by vI_s at the terminals of the rotor is proportional to the frequency of excitation f .

$$E = w L v I_s$$

where w equals $2 \pi f$ and $w L$ is the inductive resistance of the rotor at the frequency f .

The superimposed load current in the rotor is:

$$I_R = \frac{E}{\sqrt{R^2 + w^2 L^2}}$$

R being the ohmic resistance of the rotor.

$$v I_R = \frac{v^2 I_s w L}{\sqrt{R^2 + w^2 L^2}} = v^2 I_s \sin. \phi$$

ϕ being the angle of lag of I_r behind E .

The locus of $v I_r$ is therefore a circle of diameter equal to $v^2 I_s$ as represented in Fig. 4. In Fig. 5 this circle is drawn directly upon I_s .

If the constants of the rotor are known we have the angle ϕ

FIG. 5.

in function of the frequency of excitation. It is then possible to draw $v I_r$ and j_s . We suppose E_x and i_0 constant and neglect the ohmic drop of the stator winding.

The resultant of j_s and $v i_0$ must be inclined on I_s by 90° plus the angle of lag of the load current I_s behind the terminal electromotive force E_s of the armature. If therefore, with centre on the terminal of $v I_r$ and radius $= v i_0$, we cut the power-factor lines (Fig. 5), we obtain the resultant magnetomotive force i_m effective at the stator terminals for a given ampere load of the machine at any power-factor and any frequency of excitation.

The terminal electromotive force of the alternator will be

proportional to i_m if the saturation and ohmic drop of the stator winding are neglected.

Fig. 6 shows the regulation of the induction alternator at different frequencies of excitation. The curves belong to a 100-kw., 8-pole, 60-cycle, 900 effective rev. per min. machine built by the Crocker-Wheeler Co. for experimental purposes; Figs. 2, 3, 4, and 5 refer to the same machine. The curves of Fig. 6 are in perfect accord with the actual tests made on the machine, the results of which are given later on.

This Fig. shows that for each machine, that is, for each combination of resistance and leakage in any machine, there is a certain frequency of excitation below which trifling changes

FIG. 6.

in the constants of the alternator produce great changes in its potential characteristics. For small high-frequency machines an exciting frequency of about five cycles may be required, while on large machines in which the resistance and leakage may be relatively lower, the exciting frequency may be as low as one cycle.

In a similar way it is possible to study the influence of the variations in the exciting frequency in the case of the forward rotation of the field. The locus of vI_r is in this case a circle, as shown in Fig. 7. Fig. 8 gives the regulation of the same 100-kw. alternator at different power-factors for different frequencies of the field.

NOTE.—Since this machine was designed experience has taught us to design with much less variation of potential for changes of load and power-factor.

The curves in Fig. 8 show that in the case of forward rotation of the field the potential of the alternator will drop at any power-factor, due to the effect of the resistance and leakage;

FIG. 7.

but the difference in regulation between power-factor unity and lower power-factors is very small in comparison, with the results obtainable with the alternators of standard type. (The phe-

FIG. 8.

nomena in this machine are magnified by the high resistance of the rotor.)

The variation of the air-gap in these machines has a peculiar

influence on their regulation. In Fig. 6 are shown the curves of a 100-kw., 8-pole, 60-cycle, 900 effective rev. per min. induction alternator having an air-gap of 0.0625 in. (single).

Curves of Fig. 9 give again the resultant magnetizing current effective at the terminals of the armature at constant ampere load (full load) and different load power-factors for the same machine with an air-gap of 0.125 in.

Figs. 6 and 9 both refer to the case of a backward rotating field ($n_1 - n$). Doubling the air-gap of the same machine has affected very little its regulation at the frequency which is used for its excitation (about five cycles). This is due to the fact that any increase in the air-gap involves an increase in

FIG. 9.

the no-load magnetizing current of the machine, and an increase of the leakage coefficient v , and these two phenomena have conflicting influences on the regulation of the alternator.

When, however, the leakage of the machine is comparatively low, as in the case of high-speed alternators with a small number of poles, and the no-load magnetizing current is high (large air-gap) then something is gained in regulation by increasing the length of the air-gap. For instance, this is the case with turbine alternators where a large air-gap is required for mechanical reasons.

Considering now the phenomena of the system, the following general conditions are found: the current in the exciting circuit is composed of two parts or components. First, that due to the exciter electromotive force, which is the no-load magnetizing

current; secondly, the current due to the electromotive force generated in the field (rotor) conductors by the stator load current. The first of these, the no-load magnetizing current, (volt-amperes) is, for any given capacity of the alternator, inversely proportional to its speed; that is, is proportional to the number of poles of the alternator for any given generated frequency, or is proportional to the frequency of the alternator driven at constant speed.

This magnetizing apparent energy is therefore small with high-speed machines of given frequency, and small with low-frequency machines of given speed; consequently, it is smallest in low-frequency turbine alternators and is larger in slow-speed direct-connected high-frequency machines. It is to be remembered, however, that the magnetizing current is only a fractional part of the full-load current in the exciting circuit; therefore it is not necessarily a limiting condition and does not determine the size of the exciter.

The second component of the exciting current is the superimposed component, and is approximately equal in total amperes to the armature current of the alternator. The electromotive force of the exciter is proportional to the electromotive force of the alternator multiplied by the ratio of the exciting to the generated frequency. The two components of the exciting current (the magnetizing and superimposed) have the following phase relations.

When the alternator is delivering current at power-factor unity, the magnetizing and superimposed components are nearly in quadrature; when the alternator delivers current at power-factor zero, the components are nearly in phase.

If we call M the no-load magnetizing volt-amperes of the exciter, N_1 the frequency of excitation, N_{11} the generated frequency of the alternator, w the capacity of the alternator in kilovolt-amperes, we have the size of the exciter approximately proportional to:

$$\sqrt{M^2 + W^2 \frac{N_1^2}{N_{11}^2} + 2 M W \frac{N_1}{N_{11}} \sin \phi}$$

ϕ being the maximum angle of lag of the current that the alternator is called upon to deliver.

NOTE.—The size of the exciter can be exactly calculated by taking from Fig. 5 the value of the total current of the exciter for any given load and power-factor (the right phase displacement between no-load magnetizing current and load-superimposed exciter current being taken into consideration).

Thus, if the alternator is a 100-kw., 25-cycle machine excited at a frequency of 2.5 cycles, and the no-load magnetizing volt-amperes are five kilovolt-amperes, and if the alternator is called upon to deliver its full-load current at power-factor 0.5, the size of the exciter is:

$$\sqrt{5^2 + \left(100 \frac{2.5}{25}\right)^2} + 2 \times 5 \times 100 \frac{2.5}{25} \times 0.86 = 14.5 \text{ kilovolt-amperes}$$

It will then be seen that the exciter is called upon to carry a current practically equal in total amperes to the load current of the alternator, the apparent energy of which is dependent on the frequency of excitation; consequently, the aim of the

FIG. 10.

engineer is so to design his machines that they will require the minimum exciting frequency.

The following examples give the regulation characteristics of alternators of different capacities and speed when excited by alternating currents and the relative size of their exciters.

Fig. 10 shows the regulation curves of the 100-kw., 8-pole, 60-cycles, 900 effective rev. per min. alternator above mentioned, in function of ampere load of the machine when its field is excited by 5-cycle currents at constant potential (backward rotating field). For full load of alternator at power-factor 0.8 the size of the exciter is 13 kilovolt-amperes, or 13% of the size of the alternator.

Curves of Fig. 11 give the results of tests of this 100-kw. machine, results which agree very closely with the calculated characteristics of the alternator as set forth in Fig. 10.

FIG. 11.

Fig. 12 gives the regulation curves for a 500-kw., 100-effective rev. per min., 25-cycle alternator. (The ohmic drop of the stator is not considered.)

FIG. 12.

In this case the frequency of excitation (backward rotating field) is as low as 0.75 cycles. At full load of the alternator at power-factor 0.8 the size of the exciter is 42 kilovolt-amperes or 8.5% of the size of the alternator.

Fig. 13 gives the curves for a 500-kw., 60-cycle, 514 effective rev. per min. type alternator (backward rotating field. The frequency of excitation is two cycles, and the size of the exciter at full load of the alternator, power-factor 0.8, is 41 kilovolt-amperes; that is, 8.2% of the size of the alternator.

FIG. 13.

FIG. 14.

Fig. 14 gives the regulation curves of the same 500-kw., 60-cycle, 514 effective rev. per min. machine in the case of the forward rotating field. Note the small difference of regulation curves for different power-factors.

Figs. 15 and 16 refer to a 1500-kw., 25-cycle, 1500 effective rev. per min. turbine alternator. The frequency of excitation is 0.75 cycles and the exciter at full load of the alternator,

FIG. 15.

power-factor 0.8, has a capacity of 95 kilovolt-amperes; that is, 6.5% of the size of the alternator.

For all the above curves the abscissas represent either the

FIG. 16.

amperes of load or the frequency of excitation of the alternator, while the ordinates represent the resultant magnetizing current

If the saturation of the machine could be neglected this resultant magnetizing current would be directly proportional to the terminal voltage of the alternator.

Fig. 17 gives the exciting watts for different loads of the 100-kw., 60-cycle, 8-pole, alternator (at unity and lower power-factors). As shown by these curves the energy delivered to the alternator at no load is small and positive. As the alternator-load increases, the current in the rotor magnetizing circuit increases, but the watts fall to zero and reverse; that is, the current in the rotor-exciter circuit lags until

FIG. 17.

it exceeds 90° behind the exciter electromotive force; it therefore flows through the exciter against the exciter's electromotive force, just as a current delivered by a generator flows through a motor circuit against the counter electromotive force of the motor.

The all important factor in the design of induction alternators is then the excitation.

At first sight, the designing of an efficient and economical exciter to deliver multiphase exciting currents of five cycles or lower frequency, would appear to be an almost hopeless undertaking; for if an exciter of, say, 3-cycles frequency and 50 kilovolt-amperes is necessary to furnish the field and controlling current for a 500-kw. alternator, working on old lines, we should be

compelled to design a 2-pole machine of 180 rev. per min. to deliver 50 kilovolt-amperes at power-factor zero to power-factor 1.

The manufacture of such a machine would ruin any going concern. We are therefore compelled to: 1, find such a method of generating the exciting currents as will permit the use of normal speeds and consequent reduction of size of the exciter; that is, the exciters must be designed to give low frequencies at high speed; 2, to produce the desired potential gradient on the alternator, we must so design the exciter that it will have a characteristic complementary to that of the natural characteristic of the alternator it excites. These are severe conditions to impose upon any machine, but they have been met in a novel manner in the machine about to be described.

It is evident that if the field of an ordinary direct-current machine is slowly alternated, corresponding alternations in the electromotive force of the armature will occur. Such a machine could evidently be driven at any speed and would give alternating current through its commutator and brushes corresponding in frequency to the frequency of its field, but it could furnish single-phase currents only.

It is evident also that two such machines could be coupled on the same shaft, each machine having its field excited by low-frequency and phase-differing currents; and such an arrangement would generate from the two armatures two phase-differing currents, whose frequency is independent of the speed of rotation.

If now these two fields are combined in one machine; that is, if the field is a Ferraris or rotating field, instead of a simple periodic field, it is evident that a single armature with a simple commutator and four brushes placed in quadrature around the commutator will deliver two sets of alternating currents, differing in phase by the angle of the brush displacement, and at the same frequency as the rotating field, and that the figuring of the generated currents will be independent of the speed of rotation.

Such an arrangement is shown in Fig. 18, where the stator consists of a 4-pole structure having energizing coils diametrically located on opposite poles and connected to a two-phase source of excitation, while the armature and commutator deliver two-phase currents to external circuits. But this arrangement presupposes and employs a third element to furnish the original exciting current of the exciter. That device

might be called a frequency setter. It tends, however, to complicate the system and add an unnecessary element.

In order to make the exciter self exciting and self contained, and to reduce the apparatus to the simplest terms, the following scheme for excitation has been devised, Fig. 19. First let us notice that the usual method of self exciting a machine of the continuous current type is to connect the armature terminals, that is, the brushes collecting currents from the armature, to a field coil so located with reference to these brushes that currents in the coil will increase the electromotive force and current the brushes deliver; thus a cumulative action between armature and field coils continues (in ordinary practice) until limited by the saturation of the iron of the machine.

In the machine here described, a pair of brushes correspond-

FIG. 18.

ing to those of an ordinary generator is connected to a field coil, so located with reference to these brushes that the flux it produces will be displaced by a predetermined angle, dependent upon the number of phases desired. Thus for a two-phase machine a pair of brushes is connected to a field coil so located as to produce a flux, by means of which and by rotation an electromotive force is generated upon the *other* pair of brushes, while the second pair of brushes is connected to a coil so located as to produce a flux that will generate an electromotive force on the first pair of brushes. This is shown in Fig. 19, which illustrates the connection and operation of self excitation by means of two- and three-phase currents.

Let the residual magnetism of the machine be as shown in

the diagram. Then, on rotating the armature, an electromotive force will be developed on brushes 2-4. These brushes are connected to the field winding at $x-x^1$ instead of at $y-y^1$, as is usual in exciting continuous-current machines, consequently a current will flow, say from x through $a-a$ to x^1 , producing a flux through the armature at 90° to the residual magnetism. A resultant field will therefore lie between the points $y-x$ and y^1-x^1 , but this field will generate an electromotive force on brushes 1-3 and these brushes will deliver a current through $y-a-a-y^1$ in such a direction as first to *oppose* the residual magnetism and afterward to reverse its direction. At the instant that the residual magnetism is zero the only field operating in the machine is that due to the currents from the brushes

FIG. 19.

2-4; subsequently this field combines with the vertical reversed field to brushes $y-y^1$, producing a resultant with polar line between $x-y^1$. These operations being cyclic, they recur at periodic intervals, and the phenomena become continuous.

As the resistance of the energizing circuit $a-a$ is low in comparison with its inductance the currents delivered from each pair of brushes lag nearly 90° behind the electromotive forces, and therefore little energy is wasted in field excitation. This process of excitation presents many curious and interesting features. If, for example, one of the magnetizing circuits, such as x , be disconnected from the armature, the field immediately dies out, even if there is *no current in circuit* at the instant of the breaking.

The approximate calculation of the frequency of self excita-

tion as given by Mr. Faccioli will be found by considering for a moment the physical phenomena that occur.

Assume the speed of rotation of the armature to be n_1 ; let the machine be a single magnetic-circuit machine with x conductors in the armature, and y conductors on the stator. A moment's consideration of the laws of induction will show that the direction of the currents delivered by the armature to the field must be such as to produce a field rotating in the same direction as the rotation of the armature.

Let the frequency of this rotating field be N , then evidently the effective frequency of the armature conductors will be:

$$N_1 - N = N_{11}$$

We therefore have X armature conductors cut by the flux of the machine at frequency n_{11} , and Y conductors of the field cut by the same flux at frequency N , therefore there will be two electromotive forces; one on the rotor and one on the stator, for each magnetizing circuit; and as is evident the condition of equilibrium of current flow will be obtained when these two electromotive forces are equal and opposite to each other.

This condition of equilibrium will always be fulfilled for a certain frequency of self excitation; such in fact as will make:

$$\begin{array}{lcl} & & X N_{11} = Y N \\ \text{But} & & N_{11} = N_1 - N \\ \text{so} & & Y N = X (N_1 - N) \\ & & \text{and} \quad N = N_1 \frac{X}{X + Y} \end{array}$$

That is, the frequency of self excitation will be equal to the frequency of rotation times the turns on the rotor divided by the sum of the turns on the rotor and stator.

By this formula we can easily determine the winding of a machine for a given frequency of self excitation; for instance, in the case of a two-pole machine in which the speed of rotation is 900 rev. per min. (15 cycles) the number of armature conductors is 200 and the frequency of self excitation desired is three cycles, we find that the number of turns required on the stator is:

$$\frac{200 (15 - 3)}{3} = 800$$

Evidently these results are only strictly true when the resistance and leakage of the machine are zero, or not considered, as these quantities have a slightly modifying effect.

When the windings are similarly disposed in rotor and stator, it is not necessary to take into consideration the winding distribution coefficients, but the proper coefficients should be employed when the stator has salient poles.

This type of machine satisfies, therefore, the first condition laid down as necessary for a commercial exciter; for it produces low-frequency multiphase currents at normal speeds. It also fulfils the second condition—that it should deliver zero and negative power-factor currents at constant or rising potential

FIG. 20.

with much greater exactness than the ordinary type of alternator; for the reason that the armature reaction of a machine of this type may be made practically zero, because the field of the machine progresses in the same direction as the rotation of the armature and consequently tends to maintain the electromotive force at low power-factor loads, and because it may be compensated to give a positive, potential gradient.

Fig. 20 gives the voltage characteristics of a 10 kilovolt-ampere exciter in function of the amperes of load for power-factor = 1, and power-factor = 0. The frequency of self-excitation of this machine, when run at 900 rev. per min., is five cycles.

An examination of the characteristic curves of the induction alternator ($n_1 - n$) type curve 10 shows that the potential gradient of these machines is positive for load currents of unity power-factor; zero for load currents of (about) power-factor = 0.8 and negative for currents of power-factor = 0.

If, therefore, the exciter is given such a characteristic that the electromotive force of the exciter will be slightly lower when the alternator is full loaded with power-factor = 1 currents, and slightly higher when the alternator is delivering low power-factor currents, the potential of the alternator may be maintained practically constant for any variation in load or power-factor.

It is to be remembered that the exciter, when used with ($n_1 - n$ type of alternator) is *never* called upon to *furnish* power-factor unity currents, but to *receive* them, and that the magnetizing reaction of such currents upon the exciter field is exactly the reverse of that found when the power-factor unity currents are delivered; therefore, the exciter should be so designed, when used with this machine, as to give an increase of potential when delivering power-factor unity currents (that it may have a *negative potential gradient when receiving them*), as well as a slight increase of potential when delivering power-factor zero currents.

As stated in the first paragraph of this paper, the writer purposes to describe later the application of the phenomena here given to various new types of alternators. He hopes to be able to convince the members of the INSTITUTE that machines excited by continuous currents cannot compete with those employing alternating-current excitation, as the latter possess distinct advantages in simplicity, performance, and cost.

NOTE.—The phenomena accompanying this type of machine are of great interest and will be offered to the INSTITUTE in a subsequent paper.